Validation Of Lidar Retrieval Of Aerosol Extinction During Indoex With An Airborne 180° Backscatter Nephelometer

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LONG-TERM GOALS

LIght Detection And Ranging (LIDAR) can be used to estimate atmospheric optical extinction by aerosol particles along the laser path if the ratio of extinction to 180° backscattering, referred to as the "lidar ratio", is known. Lack of accurate knowledge of the lidar ratio is the largest source of uncertainty when trying to invert elastically scattered lidar signals. This translates into an unacceptably large uncertainty in the determination of particle related extinction and visual range by such instruments.

We have developed, calibrated and field-tested a new device for direct, high-accuracy measurement of 180° backscattering by particles (Doherty et al., 1999). When run in conjunction with instruments that measure total light extinction coefficient by particles, the 180° backscatter nephelometer allows for in-situ determination of the lidar ratio. Our goal is to use this new measurement capability to more realistically constrain the range of lidar ratios employed to invert elastically scattered lidar signals.

OBJECTIVES

Our current research efforts are driven by the following three objectives: (1) to make regional surveys of the lidar ratio, exploring the magnitude and variability in the quantity, (2) to assess the adequacy of current parameterizations of the lidar ratio which are based on Mie Theory using assumed or measured particle size distributions, and (3) to perform an objective calibration of the lidar retrievals of 180° backscattering, optical extinction, and the lidar ratio. The variability of lidar ratio is the result of varying chemical and physical properties of the aerosol, coupled with meteorological factors and the sources of the aerosol. The final goal can be accomplished by making coincident measurements with a calibrated Raman lidar, which is independently capable of retrieving all of these values.

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APPROACH

The Intensive Field Phase (IFP) of the InDian Ocean EXperiment (INDOEX) provided an excellent opportunity for us to accomplish our three specific objectives. The INDOEX IFP was a multi-national experiment based out of the Maldive Islands which took place from mid-February to late March, 1999. The overall goal of the project was to determine the radiative impacts of tropospheric aerosols and clouds. This was accomplished via measurements made from three aircraft, two ships, and several ground stations.

This grant allowed us to deploy the 180° backscatter nephelometer on the National Center for Atmospheric Research (NCAR) C-130 aircraft. Sarah Masonis, a PhD student in our department, ran the 180° backscatter nephelometer for the duration of the field campaign. John Ogren's group from the National Oceanic and Atmospheric Administration Climate Monitoring and Diagnostics Laboratory (NOAA-CMDL) made parallel measurements of total light scattering and light absorption, also from the C-130. They measured total particulate scattering at three wavelengths using two integrating nephelometers (TSI Inc., St. Paul, MN), one run at low relative humidity (~40%) and one at a high relative humidity (~85%) (Anderson and Ogren, 1999). Total scattering at intermediate relative humidities can be interpolated from these two measured values. The CMDL group also measured light absorption at a low relative humidity using a Particle Soot Absorption Photometer (Radiance Research, Seattle, WA). Our goal was to determine the lidar ratio at near-ambient relative humidity, allowing direct comparison between in-situ and lidar-retrieved values of the lidar ratio. To this end, we tried to maintain near-ambient relative humidity in the 180° backscatter nephelometer by insulating the instrument against heating and cooling by cabin air. This suite of instruments alone allowed us to pursue objective (1) above.

Measurements of particle size distribution and chemistry were also made on board the C-130 by Antony Clarke's group from the University of Hawaii and Meinrat Andreae's group from the Max Planck Institute, Mainz, Germany, respectively. We plan to use the findings of these two groups to calculate lidar ratios using Mie code and to compare the calculated values with our measured values. We hope to do this for several horizontal flight legs with different aerosol types.

Finally, measurements were made from a ground-based nitrogen Raman lidar by members of the Institude for Tropospheric Research (IfT) of Liepzig, Germany for the duration of the INDOEX IFP (Ansmann et al., 1992). This system was located proximal to the base of operations for the C-130 aircraft, allowing for direct intercomparison of lidar and in-situ derived profiles of 180° backscatter, particulate extinction and the lidar ratio.

WORK COMPLETED

The 180° backscatter nephelometer was installed in the NCAR C-130 aircraft and operated successfully for all 18 research flights conducted during the INDOEX IFP. While the 180° backscatter nephelometer had been shown to work in a ground-based environment, this was the first time the instrument had been operated on board an aircraft. We were able to make extensive measurements of 180° backscatter for several aerosol types under a large range of relative humidities. Unfortunately, we were unable to maintain a close match between sample relative humidity (RH) and ambient RH during profiles (see Fig. 1b). (This came about due to the rapid changes in the ambient temperature during profiles and the large thermal mass of the nephelometer). Because the RH-dependence of 180° backscatter was not directly measured, we can only make a theoretical extrapolation of the measured

values to ambient RH. Adding the capacity to make controlled-RH measurements of 180° backscatter is an important part of our future research plans.

Extinction measurements were also made for the full extent of the campaign, though several instrumentation problems preclude use of some of the data. In particular, data taken below an altitude of ~1km during vertical profiles is largely not useable for 14 of the research flights. However, data from low altitude horizontal legs is robust when proper filtering of the data is applied, and the 4 flights that are not affected by the low altitude errors have about 10-12 vertical profiles that can be processed.

To date, we have derived preliminary lidar ratios for 12 of the 18 flights and will eventually derive values for all but one of the remaining flights. In all cases, we derive lidar ratios at the 532nm wavelength of the 180° backscatter nephelometer, which is also the laser wavelength of most elastically scattering lidars, and at the relative humidity of the 180° backscatter nephelometer sample volume. We are awaiting release of the final version of the extinction data before determining our final version of the lidar ratio data set. No steps have yet been taken to calculate lidar ratios using Mie code, pending release of the particle size distribution and chemical data.

A limited number of profiles were made with coincident measurement from the Raman lidar. Coordination of all three instrument packages (180° nephelometer, extinction measurements, and Raman lidar) was more problematic than originally assumed. In some cases in-situ measurements of 180° backscatter are available for intercomparison but the exctinction measurements, and thus also the lidar ratios, are not. In some cases all three measurements are made but are separated in time by one to several hours. Finally, as discussed above, there was often a significant discrepancy between ambient RH and sample RH inside the 180° nephelometer (Fig. 1b). For all these reasons, robust intercomparisons between the in-situ and lidar measurements will not be available in many cases.

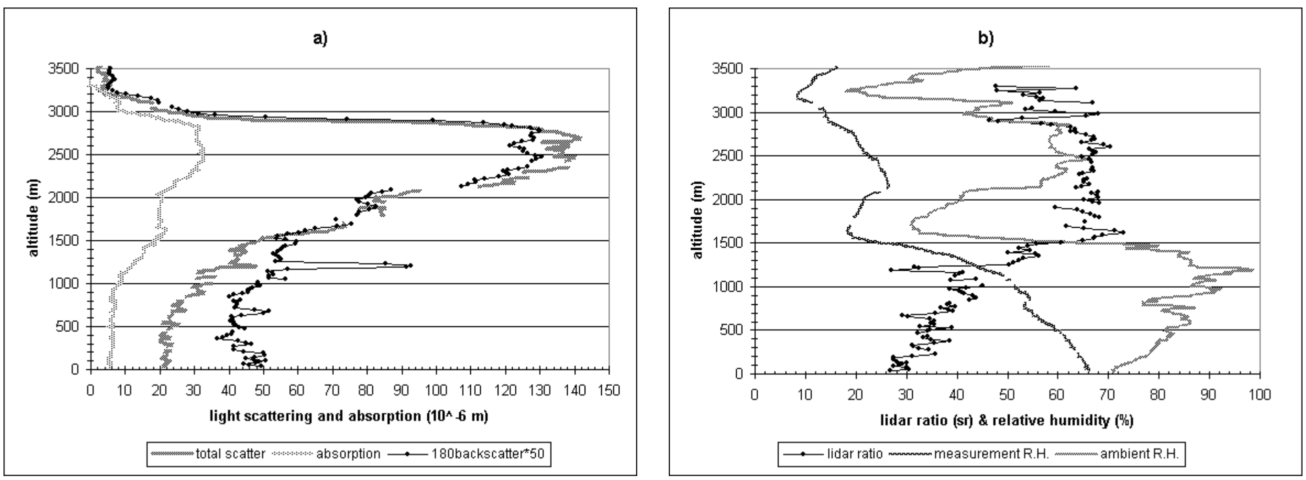
However, some quantitative intercomparison is possible. There are times when the aerosol layer is stable enough that a robust comparison can be made between measurements made several hours apart. The lidar data itself can be used to determine the aerosol layer stability. In cases where the only difference between the two data sets is the relative humidity of the measurement, gross differences in the two methods will still be apparent because we can put reasonable bounds on the expected change in 180° backscatter with RH. Also, if direct measurements of the aerosol composition and dry size distribution indicate uniformity within a vertical section of a polluted layer, vertical variations in lidar ratio can be attributed to changes in relative humidity. Comparison could then be made between lidar ratios with coincident RH, rather than coincident altitude. Future studies of the functional relationship between 180° backscatter (or lidar ratio) and relative humidity may allow us to extrapolate our in-situ data to ambient relative humidity for comparison with the lidar retrievals. Finally, because total light scattering was measured at both low and high relative humidity we are able to interpolate (using a theoretically and empirically determined model) to scattering at ambient RH. Thus a direct comparison between in-situ and lidar-derived extinction is possible any time there are coincident measurements. We are awaiting release of the Raman lidar results from IfT in order to make these comparisons.

RESULTS

Our preliminary results show a range of lidar ratios of ~20-80 for the Indian Ocean region during the winter monsoon. Conditions during these measurements were highly polluted (optical depths of ~0.25-0.50) over a thick (~2.5-3km) layer of the atmosphere. The aerosol appears to have been moderately to strongly absorbing, with a single scatter albedo of ~0.80-0.85. Horizontal flight legs at ~35m altitude often showed little coarse mode aerosol contribution, though measurements at the Kaashidhoo Climate

Observatory did indicate a significant sea salt contribution a few meters above sea-level. At higher altitudes, there appears to have been only one instance of a significant coarse mode; preliminary analysis by others indicates this may have been a dust layer.

In general, we found that the lidar ratio increased with altitude; at times it decreased to lower values near the top of the haze layer. The change in lidar ratio generally coincided with changes in relative humidity. The two parameters were often inversely related. Relative humidity can vary with air mass origin so we need to look at the chemical and dry size distribution data before we can conclude how much of the change in lidar ratio is due to changing RH and how much is due to changes in aerosol type. Preliminary results from a separate ground-based campaign at a polluted continental site in central Illinois this past August and September indicate that air mass origin likely plays a more significant role in determining the lidar ratio than does a change in relative humidity for a given aerosol type.



1. a) Elevated haze layers were often present during the INDOEX IFP, as shown here for a profile taken at 8°N, 73°E on March 13, 1999. Note that 180°-backscatter has been multiplied by 50 on this plot. b) The lidar ratio is considerably less variable than it's components and shows some dependence on relative humidity.

IMPACT/APPLICATIONS

Our participation in INDOEX comprised the first in-situ measurements of 180° backscatter and the lidar ratio. As such, the data constitute a significant contribution to the effort to determine a range of lidar ratios for atmospheric aerosols that is more tightly constrained than previous assumptions or indirect measurements. The data can be used directly in the inversion of elastic scattered lidar data from the boundary layer and free troposphere over the Indian Ocean during the polluted winter monsoon season; they can also be applied in other geographical regions with similar aerosol. This, in turn, will refine estimates of extinction and visibility reduction by the atmospheric particles.

TRANSITIONS

In addition to the Raman lidar, the INDOEX IFP also was comprised of elastic scattering lidar instruments on the C-130 aircraft, on the French Mystere research aircraft, at the Kaashidhoo Island Climate Observatory, and on board the NOAA RV Ron Brown. The groups running these instruments have each expressed an interest in using our derived lidar ratios to aid in the inversion of their data.

The instrument on board the Ron Brown was a Micro-Pulse Lidar (MPL). We have just completed a separate field experiment wherein we used a ground-based station and a horizontally pointing MPL lidar to simultaneously make in-situ and remote measurements of 180° backscatter, extinction and the lidar ratio, all at ambient relative humidity. Our lidar ratio database from INDOEX will thus be of particular utility to the inversion of the MPL data from the Ron Brown.

RELATED PROJECTS

As mentioned above, we have completed the Lidar IN-situ Comparison (LINC) campaign (Aug. – Sept. 1999) in cooperation with University of Arizona under NASA funding, which constituted a direct intercomparison between our measurements and those of a Micro-Pulse Lidar.

Our future plans focus on (i) improving our measurement capacity by adding a second 180° nephelometer for direct measurement of the humidity dependence of the lidar ratio and (ii) making measurements in a wide variety of aerosol types, including seasalt aerosols and the marine boundary layer. Extension of our survey of lidar ration values begun in INDOEX will allow parameterization of lidar ratio based on location, emission inventories, meteorological fields and chemical transport models. We hope to deploy a complete optics package (capable of measuring all the parameters that go into the lidar ratio as well as their humidity dependence) on the ground during a field experiment at Bellows Field, Hawaii in Spring 2000 and on board the ONR CIRPAS Twin Otter aircraft during ACE-Asia in Spring, 2001. Funding is being sought to permit our involvement in these campaigns.

The measurements from both INDOEX and the LINC project will directly support two planned projects for putting lidar instruments on satellites, PICASSO (Pathfinder Instruments for Cloud and Aerosol Spaceborne Observations – Climatologie Etendue des Nuages et des Aerosols) and GLAS (Geoscience Laser Altimetry Satellite). Both instruments employ 532nm elastic-scattering lidars, so the database of lidar ratios we are building will be directly applicable to inversion of their returns.

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